Organic Matter of Forest Soils

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Organic matter is a major component of soil. It has tremendous ecological significance; it determines soil health, influences ecosystem productivity, and affects climate quality. Soil organic matter (SOM) has three main fractions, fresh undecomposed residues, decomposing and partially decomposed materials, and a highly decomposed and stable product humus (it is not completely decomposed organic matter; complete decomposition of organic matter produces carbon dioxide, water, and other inorganics). Plant litters including dead leaves, stems, barks, flowers, fruits, and logs are the major sources of forest SOM. Soil animals, microorganisms, and roots also contribute to the SOM. The threshold value for organic matter in agricultural soil is 2% by weight, beyond which soil quality does not remain sustainable, but no threshold level for forest soils has so far been established. Forest mineral soils have generally 1–5% organic matter by weight. Forest soils usually have higher organic matter than agricultural soils. There are two types of organic matter in soil, active or labile and passive or stable. Humus is the stable fraction of SOM. Forest ecologists identify three types of humus: mull humus, mor humus, and moder humus depending on the degree of decomposition and integration with mineral matter, acidity, and base contents. This categorization is more pronounced in temperate and boreal forest soils. A deep O horizon also develops in these types of forests. SOM performs a variety of physical, chemical, and biological functions including aggregation, soil reaction and ion exchange and nutrient cycling in addition to supply of food and energy to soil biota.

4.1 Soil Organic Matter

SOM was defined by Baldock and Skjemstad (1999) as "all organic materials found in soils irrespective of origin or state of decomposition." Since SOM exists in various complex states in soil, it is actually difficult to measure the SOM content; most methods determine the soil organic carbon (SOC) content and estimate SOM through a conversion factor. The amount of SOM that exists in any given soil is determined by the balance between inputs from biota (vegetation, roots, microorganisms, animals) and output (CO_2 from microbial decomposition). Soil type, climate, topography, soil biota, mineral composition, management, and their interactions are modifying factors that will affect the total amount of SOM in a soil and its distribution within the profile. Any changes in the natural state of the soil systems (conversion to agriculture, deforestation, and afforestation) will lead to change in the amount and state of SOM. Mineral soils may contain on an average 5% organic matter by volume. Organic soils may have more than 80% organic matter by volume.

SOM concentrations are major indicators of soil quality. Janzen et al. (1992) observed a relationship between SOC in the uppermost 15 cm and soil productivity in agricultural point of view. They found an upper threshold level of SOC beyond which no further increases in productivity were achieved. The threshold value for SOC for these dryland sites in Alberta, Canada, was at 2% SOC. Howard and Howard (1990) suggested that the threshold value for most soils was at 2% SOC (equivalent to 3.4% SOM), below which most soils are prone to structural destabilization and crop yields are reduced. No such threshold value for SOM in forest soils could be established, although SOM influences almost all physical, chemical, and biological behavior of the forest soils.

4.2 Sources of Organic Matter in Forest Soil

There are various sources of organic matter in a forest soil. As forest soils are not usually manured except in nursery seedling development processes, all sources of organic matter in forest soils are native. Forest vegetations continuously cast litters from the above- and belowground parts. Litters are dead parts of the forest vegetation, including leaves, branches, twigs, flowers, fruits, barks, and even large logs, existing in various stages of decomposition above the soil surface. Litters may also include dead bodies of soil animals,

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insects, etc. Plant leachate, sloughed cells, and root exudates are other sources of organic matter from vegetation. To all these are added microbial cell substances. Dead aboveground and burrowing animals also significantly contribute to the forest SOM since forests are habitats of a large group of big and small animals.

Fisher and Binkley (2000) reported that there were wide variations in the amount of organic matter additions in forest soils; and all factors that affect the growth and biomass production of ecosystems influenced this addition. Important factors were climate (rainfall and temperature), topography, soil, age of forest (in case of plantations), altitude, latitude, etc. They suggested that a tropical forest may shed on an average 10 t ha^{-1} aboveground litters annually in comparison to 5 t ha^{-1} in temperate and 3 t ha^{-1} in boreal forests. Persson (2012) studied organic matter in six boreal forest types and observed that substantial amounts of organic matter from dead fine roots are continuously accumulated in the soil. Pregitzer et al. (1995) suggested that large amounts of C contained in plants recycle back to the soil through rhizosphere processes. Some investigators have quantified the root production (Vogt et al. 1986; Cheng et al. 1990; Eissenstat and Yanai 1997) and total rhizodeposition (Kuzyakov and Domanski 2000). Ludmila (2010) observed that plant residue carbon was mainly allocated on the soil surface, in the forest litter. Plant residues in the soil (dead roots + other mortmass) were estimated to contribute 10–30 % of the plant residues carbon, or 2.5–15.1 % of the total soil carbon. Soil surface and in-soil dead plant material included 60–95 % of heavily decomposed residues. In an Amazon forest on an Oxisol in Venezuela, Cuevas (1983) found that annual fine root production in the first 10 cm of soil and the root mat above the mineral soil was 8 t ha^{-1} per year. Sanford (1985) found that fine root turnover in the upper 10 cm of the same Oxisol was 25 % per month. Biomass and nutrient fluxes in litterfall for the same forest amounted to 7.6 t dry matter ha^{-1} per $year^{-1}$ (Cuevaz and Medina 1986), indicating that fine root production and turnover in forests on very infertile soils may be more important for nutrient cycling than litterfall.

4.3 Categories of SOM

There are three categories of SOM on the basis of the stages of decomposition. The categories are fresh or undecomposed organic matter, partially decomposed organic matter, and fully decomposed organic matter.

Fresh or undecomposed organic matter Fresh SOM includes freshly fallen leaves, twigs, branches, flowers, fruits, dead animal tissue, etc., if they have been incorporated into the soil. These materials begin to decompose immediately after their incorporation. It often becomes very difficult to separate decomposed and undecomposed organic matter because all organic matter in soil is subjected to decomposition immediately after their incorporation. For all practical purposes, fresh organic matter includes materials the origin and structure of which can be identified. It comprises about 1–10 % of total SOM (Lickacz and Penny 2001).

Partially decomposed organic matter It includes organic residues in soil that have undergone decomposition to a considerable extent. The structure and origin of the materials may or may not be identified. It consists of gradually decomposing detritus and partially broken down plant and animal tissues. It comprises about 10–40 % of total SOM.

Fresh, undecomposed, and partially decomposed organic matter together constitute the "active soil organic matter." They are so called because they are easily attacked by soil organisms, they are decomposed very fast, and they provide food and energy to heterotrophic soil organisms.

Fully decomposed organic matter or humus Humus is said to be "completely decomposed organic matter." It is not actually "completely" decomposed in the sense that it is still organic and complete decomposition of organic matter produces CO_2 and water with some bases. It is "fully" decomposed in the sense that it has undergone decomposition for a considerable time, say some hundreds or thousands of years, and that further decomposition proceeds extremely slow. Humus may be defined as a brown to black, amorphous, colloidal organic matter that has undergone decomposition to such an extent that it has become stabilized with soil constituents. Humus is composed of stable natural organic complexes formed by the products of biological decomposition and resynthesis. Humus is fairly resistant to decomposition due to its physical state and chemical nature. Humus is present as coating on soil particles, as gum within aggregates, and as organo-mineral complexes, which make them inaccessible to decomposing organisms. Again, humus contains refractory substances such as lignin and polyphenols. Because of these refractory substances, humus is called passive SOM. It comprises about 40–60 % of total SOM.

4.4 Functions of Organic Matter in Forest Soil

SOM performs a variety of physical, chemical, and biological functions in forest soil (Fig. 4.1). The most striking physical benefit the forest soils get from the organic matter is in the aggregation of soil particles. The effect is physical, but the processes of aggregation are all complex interactions of physical, chemical, and biological processes. Aggregation in forest soil is a natural process and forest soils are usually better structured than agricultural soils. There are plenty of litters and their decomposition products to stabilize

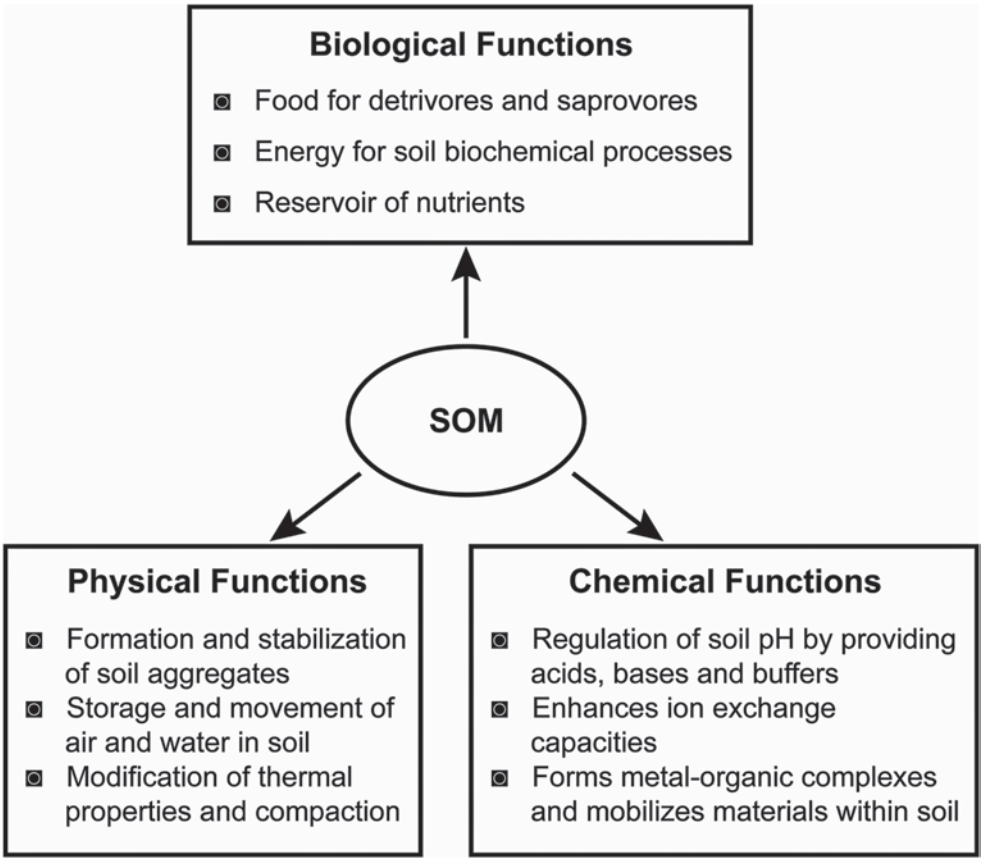
Biological Functions
Food for detrivores and saprovores
Energy for soil biochemical processes
Reservoir of nutrients
SOM
Physical Functions
Formation and stabilization of soil aggregates
Storage and movement of air and water in soil
Modification of thermal properties and compaction
Chemical Functions
Regulation of soil pH by providing acids, bases and buffers
Enhances ion exchange capacities
Forms metal-organic complexes and mobilizes materials within soil

Fig. 4.1 Schematic summary of functions of soil organic matter (SOM) in forest soil

peds. In soil, charged colloid surfaces, organic molecules, cations, and water molecules bridge each other and flocculate. At the microscopic level, clay and humic substances act as bridges between the sand and silt particles, producing microaggregates of soil (McLaren and Cameron 1996). The soil microaggregates are bound together into macroaggregates by fungal hyphae, plant roots, and other stabilizing agents at the macroscopic level (Oades 1984). Carter and Gregorich (1996) reported that the turnover time of organic matter in aggregate could be much longer than that of litter remained without aggregation. So, organic matter stabilizes aggregates, and aggregates stabilize the organic matter. It is one process of carbon sequestration in soil. In agricultural soils, tillage and other soil disturbances destroy or modify soil structure. In coniferous and broadleaf forests, SOC content was positively correlated with silt, clay, and water stable aggregates, but negatively with bulk density. Among different land-use systems studied, bulk density was the least in broadleaf forest and the highest in paddy rice fields (Han et al. 2010). Admixing of organic matter in soil increases porosity and decreases bulk density. SOM influences the hydrological properties of forest soils; it increases infiltration and percolation and decreases evapotranspiration and runoff. It increases the water-holding capacity and hydraulic conductivity.

There are a few chemical properties of soil that are not affected by soil organic matter. SOM provides chemical reactants, including carbohydrates, proteins, lignins, acids, alcohols, enzymes, etc. that take part in chemical reactions and that provide energy for other reactions to occur. SOM influences pH, redox potential (Eh), and cation exchange capacity (CEC). Forest soils are commonly acidic in character due to the continuous production of organic acids and CO_2 from decomposing litters.

Litters of some forest vegetation such as broadleaf forests of the temperate region may release substantial quantities of bases to make the underlying soils neutral to slightly alkaline in reaction. The intermediate decomposition of organic matter in waterlogged conditions may produce acid peat soils. Humus has a great surface area and a large number of electrical charges on their surfaces. So, humus has a very high CEC, 10–30 $cmol_c$ per gram of colloids. Forest soils are rich in humus and CEC.

Soil is a living and dynamic ecosystem. A healthy soil is teeming with microscopic and larger organisms that perform many vital functions including converting dead and decaying matter as well as minerals to plant nutrients. Different soil organisms feed on different organic substrates. Their biological activity depends on the organic matter supply. Organic matter addition to soils fuels the biotic population

Fig. 4.2 An image of a forest floor. (Courtesy of John Wittenberg)

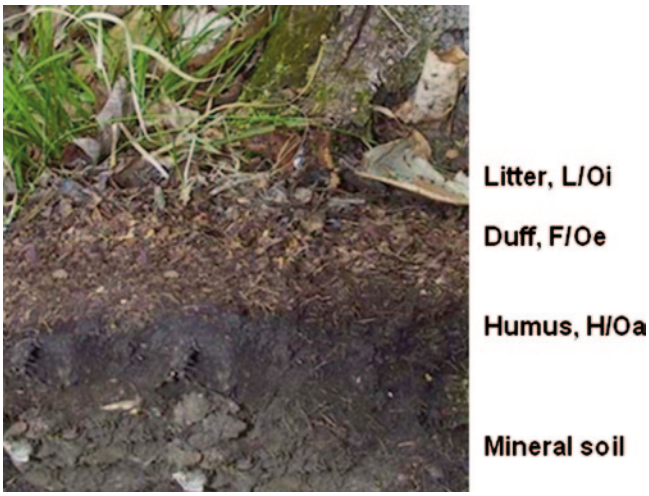

Fig. 4.3 Three zones of the forest floor

of the soil. It can be noticed when fresh litters are fallen on ground, and are attached with numerous insects and detrivores. SOM maintains the diversity and biological activity of soil organisms and plant nutrient availability. SOM is the storehouse of plant nutrients. Most N, and considerable P, K, Ca, Mg, and trace elements are continuously released in available forms from the decomposition of organic matter. SOM maintains soil quality and soil health. The most important environmental role of SOM is the carbon sequestration. Recognition of the importance of SOM in the global C balance has spurred many recent attempts to estimate the global SOM pool (Paustian et al. 1997). Increasingly, there is agreement about estimates of the global SOM pool (Batjes 1996) at approximately 1,500 Pg of organic C in the top 1 m of soil.

4.5 Forest Floor

The continuous layer of organic residues developed on the surface of a forest soil by the accumulation of fallen litters is popularly known as forest floor in forestry literature. It is actually the organic O horizon, most frequently developed on the surface of temperate and boreal forests and rarely in humid tropical forests. According to Smith and Heath (2002), the forest floor includes nonliving plant mass in various states of mechanical and chemical decay on the surface of the forest soil. Forest floor is formed by the deposition of dead organic residues from both floral and faunal components. Large vertebrate detritus may sometimes form a small part; the large part is composed of dead plant materials including leaves, twigs, barks, and woody stems (Fig. 4.2). There may also be a significant amount of fine roots in the forest floor, mushrooms, and lichens. The deposition of organic residues can form identifiable layers above the mineral soil. In a well-developed forest floor, layering can be identified, ranging from freshly fallen leaves and twigs to lower layers of humus that are at an advanced state of decomposition. The lowest layer can be amorphous and sometimes almost indistinguishable from upper layers of mineral soil (Waring and Schlesinger 1985). Organic layers above the mineral soil are usually identified as Oi, Oe, and Oa (upper to lower) or L (litter), F (fermented), and H (humus) according to a previous classification system (Federer 1982). The F layer is also called "duff" (Fig. 4.3). Distinctions among pools of coarse woody debris, the forest floor, and SOM are necessary to avoid confusion (Smith and Heath 2002). Large woody material may be excluded from forest floor. Small woody material that is considered part of the forest floor is based on diameters of recently fallen branches and stems. Diameters ranging from less than a centimeter to more than 7 cm are reported as the distinction between coarse woody debris and forest floor (Rollinger et al. 1998). Typical approximate figures for the accumulation of organic matter in forest floors are 15–100 Mg ha^{-1} in northern boreal forests, 7.5–12.5 Mg ha^{-1} in temperate broadleaved forests, and 1–2.5 Mg ha^{-1} in tropical forests (Vogt et al. 1986). The state of decomposition is a basis for distinguishing layers of the forest floor. The distinction between the lowest layers of forest floor and upper (generally A horizon) layers of mineral soil is sometimes clear. However, purely organic layers of forest floor and organic-rich layers of the mineral soil are sometimes difficult to discern. This can be even more difficult when mechanical mixing of layers has occurred (Ryan et al. 1992). Field classifications are usually based on morphology and are closely related to an individual researcher's experience (Federer 1982).

The L, F, and H layers correspond to Oi, Oe, and Oa sub-horizons, respectively, of the Pedology terminology (Fig. 4.3).

The accumulation of forest floor mass depends on rates of inputs such as litterfall and loss such as litter decomposition which are spatially (Simmons et al. 1996) and temporally

(Nemeth 1973) heterogeneous. Processes can be influenced by season, climate, and edaphic factors, as well as stand composition, age, and disturbance history (Schlesinger 1977; Mattson and Smith 1993; Binkley 1995). Decomposition rates are principally affected by quality and quantity of material as well as a favorable microenvironment (Schlesinger 1977; Hendrickson et al. 1989; Berg et al. 1996). Though quantity and quality of inputs affect carbon mass stored in forest floors, factors controlling carbon loss appear to be somewhat more important in controlling the carbon level in temperate forests (Vogt et al. 1996).

Numerous reviews report forest location and composition are associated with an average amount of forest floor mass (Schlesinger 1977; Vogt et al. 1986; Vogt et al. 1995; Vogt et al. 1996; Rollinger et al. 1998). For example, Vogt et al. (1995) reviewed a number of broad influences on soil and forest floor carbon. They demonstrated a trend of greater forest floor accumulation along a climatic gradient from tropical to temperate to boreal forests. The result of adding evergreen and deciduous classifications suggested their usefulness for predicting forest floor mass. Evidence further suggests that additional predictor variables such as soil type, stocking, productivity, or management intensity can affect forest floors, but these variables are not as consistently useful as region or forest type for making large-scale estimates (Vogt et al. 1995; Vogt et al. 1996). Climate affects accumulation and loss of forest floor mass. Longer growing seasons and warmer temperatures are associated with greater productivity and litterfall, but they also are associated with more rapid decomposition, especially if litter retains sufficient moisture and aeration (Smith and Heath 2002).

Fisher and Binkley (2000) reported physical and chemical properties of the forest floor. The L layer has freshly fallen leaves, branches, twigs, flowers, fruits, etc. They are unaltered, and their original structure is easily recognizable. The layer is loose and has a very low bulk density (even <0.2 g cm^{-3}). Bulk density increases with the stage of decomposition. Therefore, the F layer has intermediate bulk density and the H layer has the highest bulk density. The F layer is partially decomposed and the original structure of materials has largely been retained. The sources of materials are identifiable. The H layer is the humus layer which is brown to black, amorphous, and finely divided material that is relatively stable and colloidal material formed by the decomposition of overlying litter materials. It may be intimately mixed with mineral matter. Forest floor materials have high water-holding capacity. Litters have high C/N ratio which decreases with advancement of decomposition. The C/N ratio of L layer may be around 60:1 and that of the H layer may be close to 15:1. The undecomposed loose organic debris on the surface of the forest floor is not strictly included in SOM. The part of organic residues incorporated in the soil is the actual SOM.

Osman (2013) describes the significance of the forest floor in the functioning of forest ecosystems. The forest floor is a natural organic mulch of the forest soil. It reduces raindrop impact, velocity of run-off, concentration of water in narrow channels, and detachment of soil particles. It soaks water, retains water, and enhances infiltration. It improves soil structure, aeration, and drainage and reduces soil erosion. The forest floor is a spongy material and it may hold several hundred times of its own weight of moisture (Fisher and Binkley 2000). Thus, the forest floor acts as a storage tank of water which gets infiltrated gradually within the soil. The forest floor acts as a barrier to the diffusion of water vapor from the soil to the air. Evaporation of water through a forest floor is slow. Forest trees absorb nutrients from deeper parts of the soil and return much of the absorbed nutrients to the soil surface in litters. Huge nutrients are locked up in the standing forest floor materials. If these nutrients were released all at a time (as by accidental fires), they would all have been lost by washing and leaching. Litters are slowly and gradually decomposed, available nutrients are released slowly, and nutrients are absorbed by plant roots. So, there is little loss of nutrients. A large number of soil-dwelling organisms belonging to invertebrates, fungi, algae, bacteria, and archaea inhabit the forest floor. Forest floor materials provide a habitat for all of them. These organisms perform many different functions, including burrowing, pedoturbation, mixing, aggregating, and nutrient cycling. Organic residues in the forest floor are food for detrivores and saprovores. Soil organisms use organic residues as food and mediate their fragmentation, mixing, and decomposition. By this way, litter materials become soil materials. Fallen seeds are trapped in the forest floor and are preserved in it until germination.

4.6 Chemical Composition of SOM

SOM is a highly variable chemical entity because of the variable composition of different sources of organic residues. A variety of organic compounds predominate at different stages of decomposition as well. So, at any given time, SOM includes materials that are added in plant and animal residues, compounds that are formed during decomposition, substances synthesized by microorganisms during their metabolism, and compounds in root exudates and microbial secretions. In fact, SOM contains most, if not all, of the organic compounds synthesized by living organisms. SOM includes:

1. Simpler substances such as sugars, amino acids, and other small molecules
2. High-molecular-weight organic materials such as polysaccharides, proteins, waxes, lipids, lignins (Figs. 4.4 and 4.5)
3. Humus

So, SOM contains two types of substances: humic substances and non-humic substances.

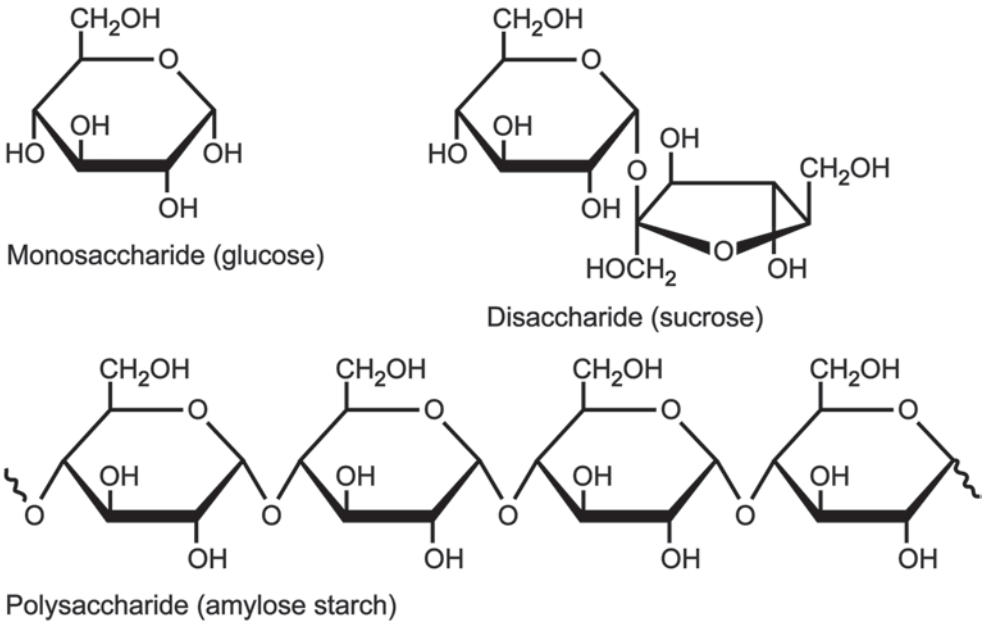

Fig. 4.4 Structures of monosaccharides and polysaccharides. (Source: http://chemistry2.csudh.edu/rpendarvis/monosacch.html)

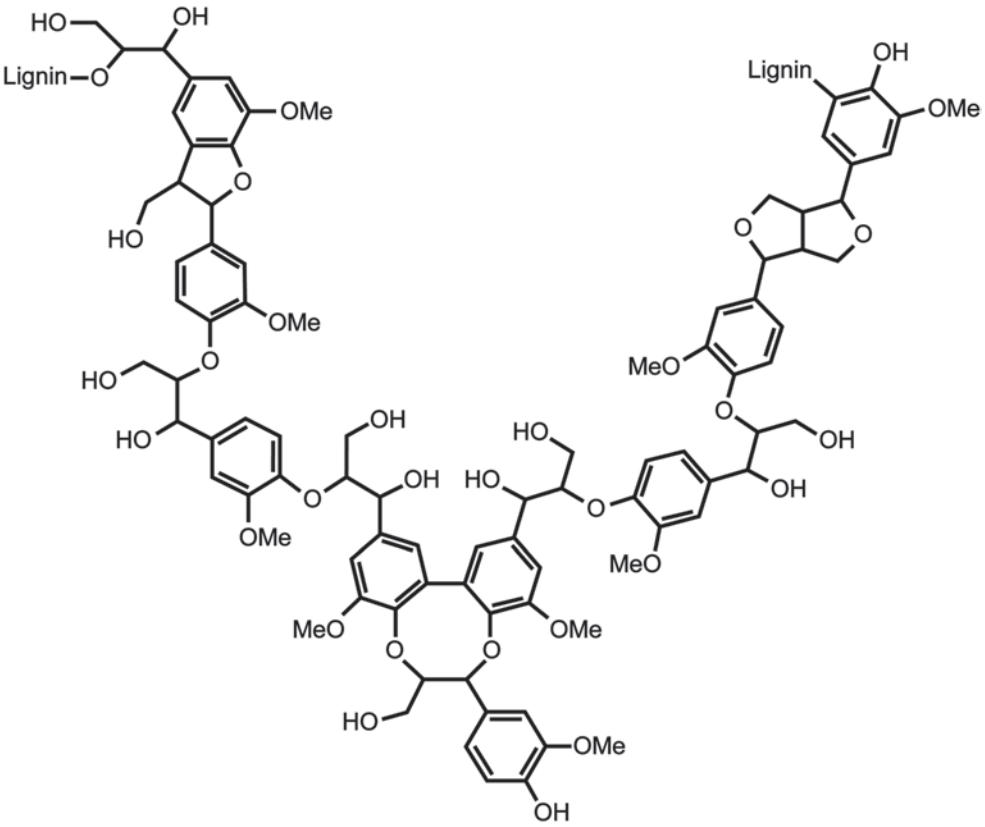

Fig. 4.5 Structure of lignin. (Source: http://www.polypompholyx.com/2012/09/far-from-the-light-of-day/)

Plant residues contain 15–40 % cellulose, 10–43 % hemicellulose, 25–40 % lignin, 1–10 % waxes and lipids, and 1–15 % proteins (Schulze et al. 2005). Microbial decomposition proceeds very fast after the addition of organic residues and slows down gradually. Susceptible or "labile" substances such as sugars (Cheshire 1979), amino acids (Stevenson 1982), other organic acids (Stevenson 1967), celluloses, etc. are quickly lost and "stable" or resistant substances such as lignin increase in proportion. Some carbohydrates and proteins are newly synthesized by microorganisms for their body

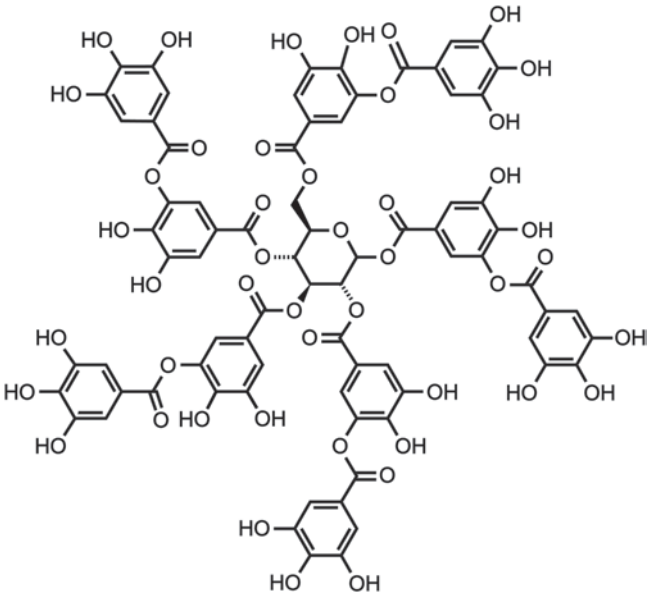

Fig. 4.6 Structure of polyphenol. (Source: http://en.wikipedia.org/wiki/Polyphenol)

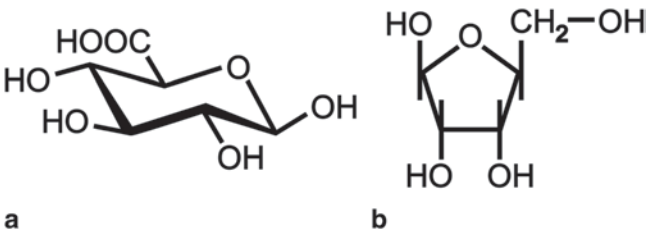

Fig. 4.7 Structure of uronic acid (**a**) and pentose sugar (**b**). (Source: http://en.wikipedia.org/wiki/Uronic_acid)

materials. These substances are also added to soils after their death. Microbial polysaccharides and proteins form complexes with lignin and other compounds rich in polyphenols and accumulate in humus (Fig. 4.6) (Coleman et al. 2004).

Some carbohydrates may be detrital, in that they originally entered the soil in plant debris, but most carbohydrates are thought to be products of microbial synthesis in situ. Hydrolyzed products of soil polysaccharides are pentoses, hexoses, deoxyhexoses, hexosamines, and uronic acids (Fig. 4.7) (Jenkinson 1988).

There is a considerable amount of amino acid polymers, such as peptides, and a small quantity of amino sugars and free amino acids. Peptides and polypeptides generally remain linked with other organic fractions, and with clay and polyvalent cations. They are stable substances which predominate with lignins in humus (Fig. 4.8).

Humic substances are defined as condensed polymers of aromatic and aliphatic compounds produced by the decomposition of plant and animal residues and by microbial synthesis. They are amorphous, dark-colored, and hydrophilic, with a wide range in molecular weight from a few hundreds to several thousands (Evangelou 1998). Three fractions of materials may be obtained during the acid–alkali fractionation of humus. They are humic acid, fulvic acid, and humin (Kononova 1966). But these fractions do not represent any discrete group of compounds; they are actually products obtained in different steps of the fractionation procedure. These fractions, however, provide a convenient way of describing the composition of humus. Chemical characteristics of these fractions are mentioned as follows (Figs. 4.9, 4.10 and 4.11):

1. Humic acid—soluble in dilute alkali, but precipitates in acid solution
2. Fulvic acid—soluble both in alkali and acid solutions
3. Humin—insoluble both in alkali and acid solutions

Generally, humic and fulvic acids have a similar structure, but they differ in molecular weight and elemental and functional group contents. Fulvic acid is lower in molecular weight and contains more oxygen-containing functional groups and elemental oxygen, but less nitrogen and carbon per unit weight than humic acid (Schnitzer and Khan 1972; Sposito et al. 1976; Schnitzer 1991). According to Aswathanarayana (1999), humic acid contains 560, 47, and 355 g kg^{-1} C, H, and O, respectively, while fulvic acid contains 457, 54, and 448 g kg^{-1}, respectively.

4.7 Dissolved Organic Matter in Forest Soil

Part of the SOM is water soluble and is encountered in the soil solution as dissolved organic matter (DOM). DOM has an important role in soil solution chemistry, soil forming processes, elemental cycling, and plant nutrition (Stevenson 1983; Duchaufour 1991), and in the transport of elements within the soil (Qualls et al. 1991). Additionally, DOM has been shown to affect the stabilization of aggregates (Kuiters 1993). DOM is present in all ecosystems. It occurs in forms that range in size from simple amino acids to complex high-molecular-weight DOM. The origin, function, and fate of these compounds in terrestrial ecosystems are only partially understood (Neff and Asner 2001).

Huang et al. (1998) found that DOM was the most oxidized and microbially processed fraction of SOM. Kaiser and Guggenberger (2000) showed that the carbohydrate and lignin profiles of DOM most resembled that of organic matter found in the clay fraction of the mineral soil, which is generally considered to be a highly altered biological reaction product. Thus, DOM released from fresh plant material and litter would seem to undergo transformations, transport reactions, and lag times prior to exiting mineral soil profiles (Sanderman et al. 2008). While these studies point to the significance of highly altered OM found within the mineral soil as a major source of DOM, other investigations (Aufdenkampe et al. 2001; Kaiser et al. 2001; Hernes et al. 2007)

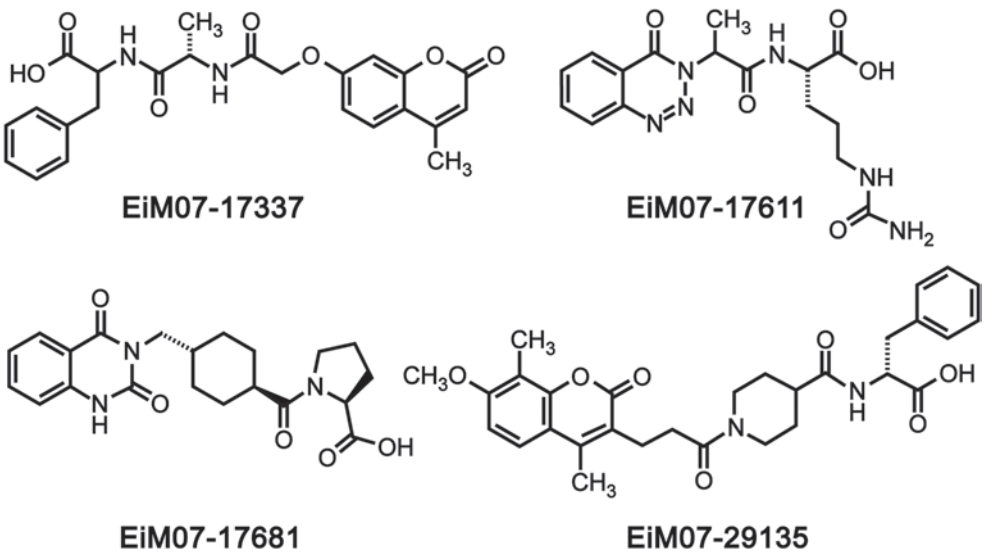

Fig. 4.8 Structure of peptides. (Source:http://www.google.com.bd/imgres?imgurl=http://blogbio-syn.files.wordpress.com/2013/09/peptides-1)

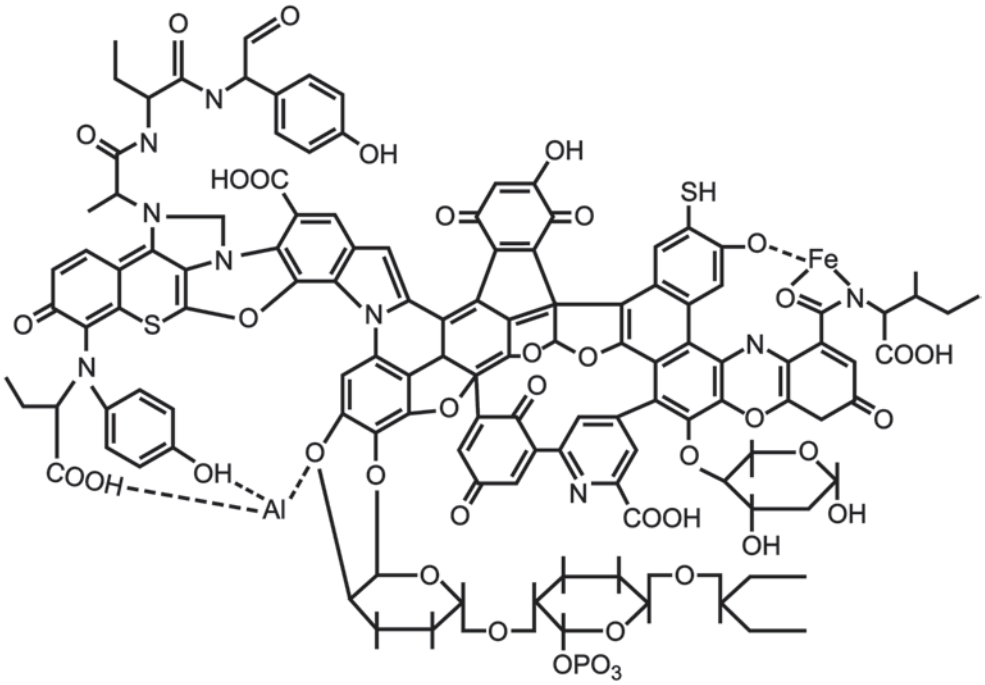

Fig. 4.9 Structural model of humic acid. (Source: http://eximedlab.com/index.php?p=research&sp=1)

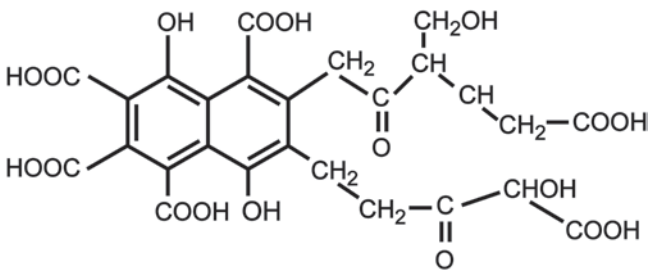

Fig. 4.10 Model structure of fulvic acid. (Source: http://www.humet.com/acatalog/humifulvatescience.html)

have stressed the importance of preferential or selective adsorption of surficially derived DOM in controlling the DOM composition in mineral soils. Despite the more dynamic nature of the potential DOM pool relative to bulk SOM, the field-collected DOM, even within the O horizon, is rarely dominated by the low-molecular-weight, hydrophilic, and highly labile organic compounds which are suggested by studies that examine water-extractable OM from fresh litter material (Kalbitz et al. 2003). Studies with nuclear magnetic resonance (NMR) reveal that DOM resembles highly altered and chemically recalcitrant organic matter rather than fresh plant residues.

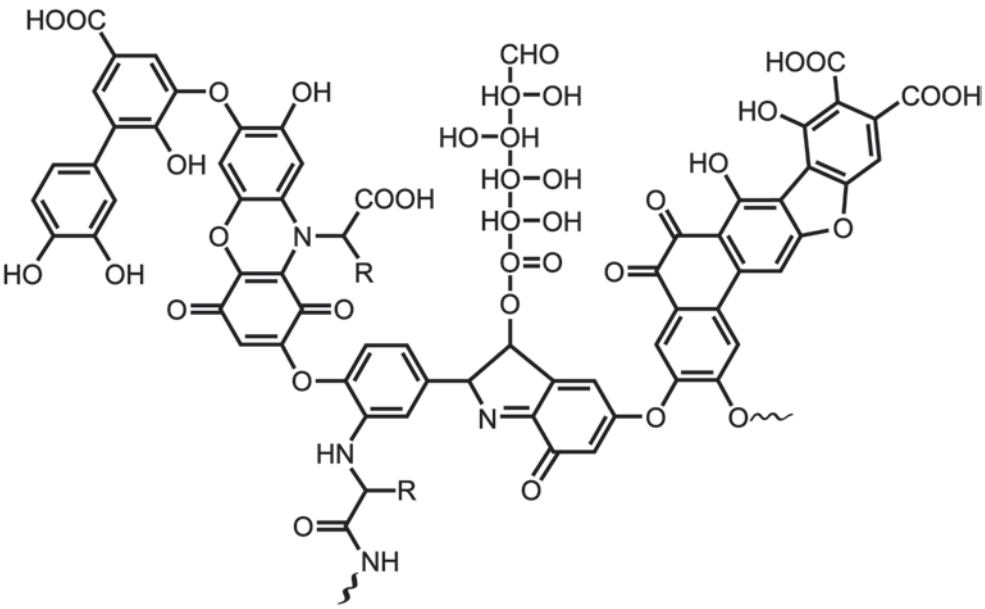

Fig. 4.11 Structure of humin. (Source: http://en.wikipedia.org/wiki/Humic_acid)

DOM is a small fraction but it strongly concerns with carbon and nitrogen dynamics in forest ecosystems (Kalbitz et al. 2000). Biodegradation of DOM, which is probably most active in surface organic horizons, is a process to release gaseous carbon from soils to atmosphere by preferential metabolization of carbohydrates leaving recalcitrant constituents mainly composed of lignin-derived phenols (Kalbitz et al. 2003). The sorption of DOM onto soil minerals is one of the most important geochemical processes for preservation of carbon and nitrogen included in lignin-derived and microbial synthesized acidic compounds in soils (Guggenberger and Kaiser 2003). After passing through soil systems, DOM might be discharged into aquifers as allochthonous DOM in natural water systems, stream, river, ocean, and so on (Lobbes et al. 2000; Amon and Benner 2003).

DOM is probably the most bioavailable fraction of SOM (Marschner and Kalbitz 2003) and contributes significantly to nutrient cycles (Qualls 2000). Pizzeghello et al. (2006) suggested that DOM plays an important role in forest ecosystems in the following ways:

1. It is a major mode of nitrogen and phosphorus export in forest ecosystems.
2. It determines the balance and accumulation of nitrogen, phosphorus, and possibly of carbon, in long-term soil development.
3. Being normally acidic, and displaying a powerful metal-complexing activity, DOM is deeply involved in mineral weathering, metal toxicity mediation, and metal export to water bodies.
4. It provides a potential source of carbon for microbial growth.

Many authors suggest that tree species and ground vegetation affect the quality and quantity of DOM in the soil (Hongve et al. 2000; Kaiser et al. 2001; Park et al. 2002), but others believe that tree species have little effect on the DOM composition and chemical reactivity (Souminen et al. 2003). According to Qualls (2000), 22–41 % of the C in the freshly fallen autumn leaf litter of a deciduous forest is water soluble.

The constituents of DOM may influence the growth of forest trees. For example, Pizzeghello et al. (2006) observed that the growth of *Picea abies* seedlings was influenced by the phenolic acid content of soil. At concentrations between 1 and 100 μM, phenylacetic and protocatechuic acids inhibited root growth to the same extent as indoleacetic acid, while p-hydroxybenzoic acid had a stimulating effect comparable to that of gibberellic acid. The aliphatic and phenolic acids appear to be related to plant strategies that influence soil fertility affecting plant growth through rhizodeposition. The role of low-molecular-weight aliphatic and phenolic acids as molecular markers of ecosystem function is also important.

4.8 Types of Humus in Forest Soils

Forest soil humus is one of the most interesting components of the forest environment. Humus is responsive: Humus type and characteristics are indicators of forest treatment and, to some extent, of site quality. Foresters find great differences in the humus beneath various kinds of forests and suggest that these differences influence the physical, chemical, and biological properties of forest soils. There are three major types of forest humus: mull humus, mor humus, and duff mull or moder humus (Hoover and Lunt 1952). These humus types differ in the presence or absence of a humified layer; the degree of incorporation of organic matter into the upper mineral soil layer; and the structure, thickness, and organic matter content of the humus layer (Fisher and Binkley 2000).

Mull humus is the brown to black, amorphous, colloidal, decomposed organic matter that is intimately mixed with the mineral matter of the surface soil. Mull humus is less acid, has higher CEC, has a crumb structure, and is rich in bases (Barrat 1964). It generally develops under broadleaf forests on fertile calcium rich soils. Mull is a type of humus characteristic for chestnut soils, phaeozems, rendzinas, and others soils (Alfisols, Spodosols, Mollisols). This type of humus may also arise under grass vegetation. Mull is a well-humified organic matter, which is produced in a very biologically active habitat. This type of humus is characterized by a neutral pH, C/N ratio nearing to 10, and ability to create stable mineral–organic complexes. It represents true humus.

According to Fisher and Binkley (2000), mor humus is a superficial deposit of fibrous and partially decomposed organic matter that is acidic in reaction and poor in bases. It generally develops under coniferous forests and moorland forests in poorly fertile soils. This humus arises under conditions of low biological activity in soil. The mineralization of organic matter proceeds slowly and creates layers, which maintain a structure of vegetable material. It resembles peat. Acidophilic fungi and low active invertebrates participate in transformations of plant residues. Acidic forest soils tend to have a buildup of mor humus on the surface caused by the absence of earthworms below pH 4.8 and reduction in fungal and bacterial activity. It is low in nitrogen and wide in C/N ratio, 20–40. Mor humus is also called raw humus. In mor humus, the H layer rests on the surface soil with practically no mixing with the underlying mineral soil. The biochemical composition of litters is important in the formation of different types of humus. For example, stabilized leaf proteins play an important role in the formation of mor humus. These proteins, stabilized in the dying leaf by tannin-like materials, are so resistant to decomposition that the tissues in which they occur accumulate on the surface of the mineral soil. Withholding of supplies of available nitrogen in these proteins may also delay decomposition of other materials.

Duff mull or moder humus is intermediate or transitional between mor and mull, characteristic of fairly acidic soils often under trees with hard litter such as beech or oak. It is frequently formed in sod-podzolic soils, loesses, and mountain grassland soils. The organic horizons with moder humus consist of thin litter (2–3 cm), which gradually, without bounds, passes on to humus-accumulative horizons. Moder is a type of medium humified humus. C/N ratio is within 15–25. Here, earthworms are usually absent and the litter is mainly decomposed by fungi and arthropods (ants, mites, springtails, millipedes, woodlice/sawbugs, etc.), leaving a mix of plant fragments and mineral particles held together by arthropod fecal material. This gives a loose, crumbly texture to the humus (Thomas and Packham 2007).

According to Kononova (1966), there are three types of humus:

First type of humus is characteristic of podzolic soils, gray brown soils, and lateric soils (Spodosols and Alfisols) under forest communities. In this humus predominate humic acids, thus humic acid/fulvic acid ratio is below 1. Humic acids indicate a small extent of aromatic rings condensation and they are approximate to fulvic acids. Considerable hydrophilic properties of humic acids favor the creation of chelates with polyvalent cations and ability to displacement deep into profile of soil. Considerable mobility of this humus favors the process of podzolization.

Second type of humus is characteristic of phaeozems, rendzinas, black earths, and brown soils (Alfisols and Mollisols). The humic acid/fulvic acid ratio is greater than 1. The extent of aromatic rings condensation is high in humic acids, which cause their hydrophobic properties and inability to create chelates. Humic acids are strongly connected with the mineral portion of soil in this type of humus.

Third type of humus is characteristic of semidesert soils. In this humus predominate fulvic acids fraction, whereas arise of humic acids is limited. Beyond this, humic acids are largely bounded with mineral portion of soil.

4.9 Organic Matter Content in Forest Soils

The forest soil has high organic matter content at the surface, where litterfall has contributed. Subsoil gets organic matter from the occasional death and decay of tree roots. However, SOM in a forest soil decreases rapidly with depth. In the native grassland, on the other hand, organic matter content is also high at the surface, but it drops off slowly with depth. The organic matter content in soil depends on soil conditions, vegetation cover, topography, hydrological conditions, elevation, and soil management. The two major natural variables which affect forest SOM are temperature and moisture. Temperature affects organic matter accumulation in two ways. First, plants tend to grow faster and produce more total mass as temperatures increase. Second, however, and usually overcoming the first point is that, as temperatures increase, microbial activity, including organic matter decomposition, also increases. For this reason, relatively little organic matter is found to persist in the forest floor of a tropical rain forest. Microbial activity is just too intense to allow organic matter to accumulate there. On the other hand, soil moisture has a little more predictable effect on SOM. As rainfall increases, the total plant production of organic matter increases, and so SOM increases. It becomes complex, however, when temperature and moisture effects are put together. In the continental USA, east of the Rocky Mountains, the general trend is that SOM content increases from west to east and from south to north. The west-to-east trend is because of

increasing rainfall, while the south-to-north trend is because of lower temperatures preserving the organic matter that is produced. One natural exception occurs where water accumulates to a degree that the soil is flooded for long periods of the year. In swamps or bogs, the excess water produces a shortage of oxygen as a consequence of which organic matter builds up regardless of the temperature until the swamp is drained.

Total grassland area of the world is $3{,}040 \times 10^6$ ha, while total forest area is $4{,}050 \times 10^6$ ha. There is almost no grassland in Histosols, and no forest in Aridisols or Mollisols. Most of the potentially arable land not yet cultivated is grassland, and the greater part of the grazeable land not yet used is now savannah or forest. A large part of mountain soil is barren land. The soils of humid regions, such as Oxisols, Alfisols, Ultisols, and most of the Inceptisols and Entisols, are forested if they are not used for crops or grazing. These various types of soils have tremendous variation in their organic matter contents. Some examples are given subsequently.

Organic matter content is usually 1–5% of the dry weight in forest soil and it decreases with depth. The carbon content is about 58% of the organic matter content. There are some forest soils which either have higher organic matter content or are organic soil in nature. Under natural conditions, the content of organic matter in soils of stable forest ecosystems is constant; the rate of decomposition equals the rate of supply of organic matter from vegetation. The equilibrium is disturbed when forests are burned or cleared, and the land is used for agriculture or otherwise. The decline is rapid in the first few years after deforestation and gradually slows down over the next 10–50 years (Buringh 1984). A soil, with a bulk density of 1.5 and a carbon content of 3% in the 0–25 cm layer, 1% in the 25–50 cm layer, 0.3% in the 50–75 cm layer, and 0.1% in the 75–100 cm layer, contains 165 t ha^{-1} total organic carbon within 1 m soil depth. The 0–25 cm layer contains 113 t ha^{-1} or 68% of the total. In Mollisols (grassland soils), the total soil carbon is more than 200 t ha^{-1} and the surface layer of 0–25 cm contains only 25% of the carbon because the humus layer is very deep. The average percentage of organic carbon of 1 m depth in forest soils belonging to different soil orders is given in Table 4.1.

Organic matter contents of 1 m upper soil range from 0.87 to 2.50%. If 70% of organic matter concentrates in upper 25 cm depth, then the range becomes 2.60–7.5%. In Table 4.1, no figures for Aridisols and Mollisols are given for forestlands, because Aridisols are soils usually found in deserts and Mollisols are usually found in prairies. Histosols represent the typical organic or peat soils of coastal swamps, which generally have not been reclaimed except for some small areas in Western Europe and North America (Buringh 1984).

Table 4.1 Estimated forest areas in different soil orders and their average organic matter content up to 1 m depth from surface. (Data extracted and calculated from Buringh 1984)

Soil orders	Estimated forest land (10^6 ha)	Average soil organic matter content			
		Virgin forest		Secondary forest	
		t ha^{-1}	%	t ha^{-1}	%
Alfisols	800	270	1.80	200	1.33
Aridisols	0	–	–		–
Entisols	550	230	1.53	170	1.13
Histosols	100	375	2.50		–
Inceptisols	650	270	1.80	200	1.33
Mollisols	0		–	–	–
Oxisols	450	240	1.60	180	1.20
Spodosols	250	130	0.87	100	0.67
Ultisols	400	240	1.60	180	1.20
Vertisols	50	190	1.27	140	0.93
Mountain soils	800	200	1.33	150	1.00
Total	3,040		–		

4.10 SOM Turnover

The turnover of an element in a pool is generally determined by the balance between its inputs and outputs to and from the pool. Turnover is most often quantified as the element's mean residence time (MRT) or its half-life (T1/2). The MRT of an element in a pool is defined as 1) the average time the element resides in the pool at steady state or 2) the average time required to completely renew the content of the pool at steady state. The term half-life of SOM is the time required for half of the currently existing stock to decompose. MRT values can be estimated by different methods and different values are obtained with these methods. Also, variations occur due to differences in vegetation, climate, soil type, and other factors. The ^{13}C method is generally used in medium-term observations or experiments (5–50 years); hence, this method gives an estimate of turnover dominated by relatively recent inputs and C pools. In contrast, the oldest and most recalcitrant C pools dominate estimates by radiocarbon dating because of the long-term time frame (200–40,000 years) that this method measures (Goh 1991).

SOM is the major reservoir of carbon in terrestrial ecosystems, storing some 1,500 Pg (1 Pg = 10^{15} g) of carbon in the upper meter of mineral soils (Jobbagy and Jackson 2000). This is slightly more than twice the amount of carbon present in the atmosphere as CO_2. However, knowing the size of the soil carbon storage in soils is enough alone for predicting its potential to influence atmospheric CO_2 concentrations. An important area of understanding is the role of SOM in carbon cycling. Not all of the carbon in soils interacts with atmospheric CO_2 on the same time scale. For this reason, SOM may be categorized into several pools with characteristic turnover times of year, years to decades, and over several hundred years (Parton et al. 1987). Most of the

roughly 80–160 Pg C in surface litters (Matthews 1997) and an estimated 200–300 Pg C in SOM are in forms that accumulate and decompose on time scales of a century or less (Schimel 1995; Potter and Klooster 1997). The remainder, constituting the majority of carbon stored in mineral soils, is stable on time scales of centuries to millennia. In general, forest clearing is associated with soil C loss and regrowth is associated with soil C gain in temperate and tropical forest ecosystems (Camargo et al. 1999).

Primary production and microbial decomposition are the overall biological processes governing inputs and outputs and, hence, SOM turnover. These two processes and their balance are controlled by complex underlying biotic and abiotic interactions and feedbacks linked with the state factor model of soil formation (Jenny 1980). Climate, especially temperature and precipitation, affects both production and decomposition of SOM. Vegetation type affects production rates and the types and quality of organic inputs (belowground vs. aboveground, amounts of structural tissue, C/N and lignin/N ratios), as well as the rates of water and nutrient uptake—influence decomposition rates. Disturbance or management practices also exert considerable influence on SOM turnover via direct effects on inputs and outputs and through indirect effects on the factors controlling these fluxes.

Study Questions

1. What is soil organic matter? What are the sources of organic matter in forest soils? Give an account of the functions of organic matter in forest soil.
2. Explain the structure and properties of a forest floor. Narrate its significance. Why are tropical forests usually lacking a well-developed forest floor?
3. Define humus. Explain why humus is relatively stable in soil. Discuss different types of humus in forest soils. Discuss the turnover of SOM with emphasis on humus.
4. What do you mean by DOM? Discuss the chemical nature of DOM and explain the significance of DOM.
5. Give an account of the chemical composition of SOM. Explain that humic acid, fulvic acid, and humin are products of acid–alkali fractionation procedure; they are not discrete chemical compounds.

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